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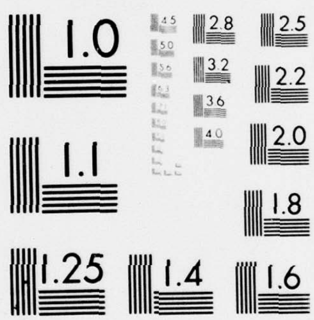
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GAMBINO

AN EXPERIMENTAL DIGITAL INTERACTIVE FACILITY (U)

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INTRODUCTION

The U.S. Army Engineer Topographic Laboratories (USAETL), Fort Belvoir, Virginia, has developed an extensive, interactive digital image processing facility to efficiently conduct research in areas such as military intelligence, digital product generation for weapon systems, and digital mapping. The facility is called the Digital Image Analysis Laboratory (DIAL), and it began to evolve from a general purpose computer-oriented system approximately 4 years ago. It is supported by the Defense Mapping Agency (DMA), the Corp of Engineers, and DARCOM's Army Space Program Office (ASPO).

The research effort in digital image processing began in a modern computer environment 6 years ago. As experience was gained, it became apparent that it was impractical to produce digital products in this environment because of the computer's inefficiency relative to existing production equipment using electro-optical technology. A classic example of this in the mapping sciences is seen in the development of stereocompilation equipment during the past 20 years where the computer is never used to perform the basic correlation function. Therefore, it was necessary to create a digital system which would at least indicate its competitive qualities relative to current production systems, and it placed the research on a higher plane as opposed to simply testing algorithms on general purpose computers.

Data volume is a characteristic of digital image processing and it significantly impacts the resources of conventional computer systems by locking out other tasks in a multiprocessing computer environment. We wish to use this characteristic to distinguish between digital image processing and computer graphics where, generally speaking, the former implies at least six times as much data is being manipulated as compared to applications involving computer graphics. At least 64 grey levels are represented on a good quality photograph which requires six bits to digitally represent a spot (pixel) while graphics generally require only one bit to represent lines.

These adverse consequences upon conventional computer systems drive digital image processing research in three directions. One lies in the area of efficient algorithm development, such as the Fast Fourier Transform (FFT). Another is in the direction of efficient system software development where lack of concern has caused execution times of up to ten times longer for the same algorithm on systems with similar hardware. Finally, digital image processing spurs research in digital architecture which includes display technology. As we describe DIAL and various applications in this paper, we see that all three areas have been considered in the system development.

HARDWARE

We will not elaborate in detail about the hardware since much of it involves standard computer components. However, we will point out those nonstandard hardware items which were acquired to build the interactive system. This comment implies that the software and hardware together make up a system which is not commercially available through the standard computer manufacturer and that there are no similarities between this software system and commercially available interactive graphics software packages.

Figure 1 is a block diagram of the DIAL system. It consists of three subsystems: the host control processor (CDC-6400), the associative array processor (STARAN), and the image softcopy/hardcopy/digitizing subsystem (COMTAL 8300, DICOMED D-56, D-47, D-36; PDP-11/50) [1]. Each subsystem operates either as a stand-alone or together with other subsystems as an entire system. Digital interactive image processing goes on concurrently with testing and software development on the host processor. Imagery can be passed from one subsystem to another via commands from the Tektronix terminals whereby processing might take place in STARAN and the results viewed on the softcopy system in a matter of seconds.

CDC-6400 PROCESS CONTROLLER SYSTEM

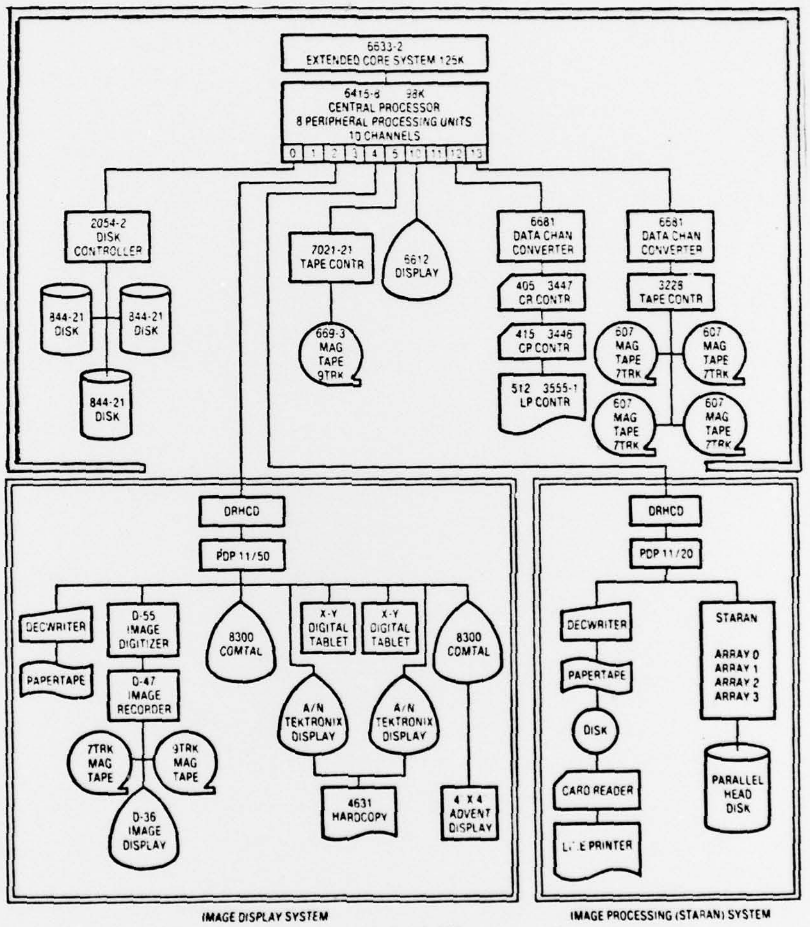

Figure 1. DIAL'S THREE SUBSYSTEMS

STARAN. Developed and built by Goodyear Aerospace Corporation, Akron, Ohio, the STARAN represents one of the aforementioned nonstandard hardware components of the interactive system. It is the parallel processing part of the system and only those image processing functions which can be executed faster using its digital, parallel architecture, are transmitted to it for processing. All applications implemented on STARAN have required a considerable rethinking of the problem in order to take full advantage of its architecture, which is unique among all digital processing systems.

We will discuss only the characteristics of the arrays of STARAN in this paper. Additional information can be found in [2]. There are four arrays in the STARAN interfaced to the interactive system. Each of the four arrays is composed of 256 words, each having 256 bits for a total of 1,024 words and 262,144 bits. Each array contains 256 simple processing elements. Therefore, 1,024 processing elements are available to perform an operation simultaneously. Further, each processing element acts on an independent data stream, thereby offering the theoretical possibility of acting simultaneously on 1,024 independent data streams. Thus far, Input/Output restrictions have kept us from taking full advantage of this very large processing bandwidth. A simplified diagram of one array is shown in Figure 2. The arithmetic operations are bit serial but

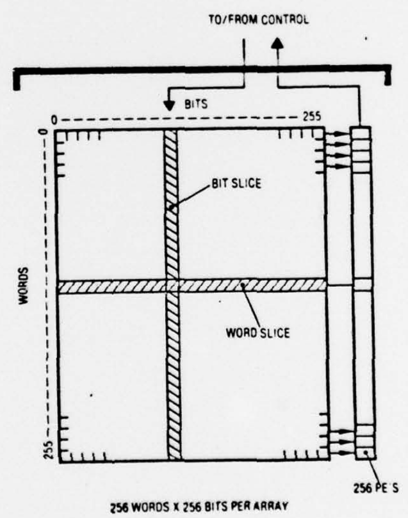

Figure 2. Associative array

word parallel -- architecturally the inverse of conventional computers.

Another unique feature of the array is its content-addressed (associative) memory. This allows identity of all elements meeting a certain criteria in a single memory access whereas the conventional computer searches its data file one element at a time. This feature will find widespread use in data base management and lead to a logical structure of data not now utilized in commercially available data management software packages. As a matter-of-fact, we are investigating a relational data structure as opposed to the network and hierarchical structures prevalent in current data management systems. The relational structure is suited to associative memories and it also more nearly represents the way people usually structure data; namely, as flat files like in telephone directories.

CHANNEL COUPLERS. These hardware devices represent other non-standard computer components and were procured to interface the host processor, which is the Control Data Corporation (CDC)-6400 computer, to the STARAN and image display subsystem. The channel coupler permits up to four digital image formats to be programmed and these formats are transferred across these channels at approximately 4.8 megabits/second. However, because of system software overhead, the effective rates are approximately 2.5 megabits/second. These channel couplers were built by the Digital Equipment Corporation (DEC) and detailed information concerning them is available elsewhere [3].

PDP-11/50 COMPUTER. The PDP-11/50 provides the interface between the image display subsystem and the CDC-6400 computer through the channel coupler. In addition to serving as this interface, it is used as the real-time controller for all devices connected to it. It also allows local processing of imagery as opposed to performing operations on the CDC-6400 computer or STARAN. Operations such as grey-scale remapping and pseudocolor encoding are performed "locally" since these kinds of image processing operations do not require the power of the other computers.

Many of these simpler operations can occur concurrently with processing on the CDC-6400 or STARAN. For example, while the PDP-11/50 is remapping grey shades, the CDC-6400 can be pseudocolor-encoding grey shade data stored in the display system.

DIGITAL IMAGE DISPLAYS. The image display units consist of two COMTAL 8300-SE systems featuring refresh storage of three 512 x 512 1-bit graphic overlays in each system. We will see the graphics capability in the photos reproduced later in this paper. The reader should keep in mind that these displays are high resolution and are much more expensive than the home television variety. High resolution is a necessary factor if serious photo interpretation for military intelligence operations is to take place in a digital environment as compared to work at the conventional light table.

In concluding this section on hardware, we must state that the characteristics of each of the subsystems have been presented in only very general terms and only very briefly. We have not said much about the CDC-6400 computer itself, but let it suffice to say that it acts as the controller for the interactive system and that it has some features which are well suited to digital image processing. All told, five different computers make up the interactive system. Although each of these computers is not explicitly mentioned in this paper, they make up parts of the larger computers. For example, the CDC-6400 has eight peripheral processing units (PPUs) which are 12-bit, 4,096-word minicomputers. These control all the peripheral hardware and much of the operating system software. Two of these PPUs are dedicated to nonstandard use in that one is used for interfacing STARAN to the system and the other for interfacing the PDP-11/50. These two units are used to accomplish all the control and data transfers between the subsystems. The other computer not previously mentioned is a PDP-11/20 used to control the internal operation of STARAN. Therefore, the PDP-11/50, PDP-11/20, PPU, CDC-6400 and STARAN make up the five different computers used in the development of the digital interactive system. Needless to say, a very sophisticated system software development program was undertaken to make the interactive system operational.

SOFTWARE

Two bodies of software were developed for use by non-system personnel. It is via these software systems that users and applications personnel develop their programs to perform intelligence and mapping functions. Relieving these people from system software concerns should speed research in digital image processing. The two bodies of software are called the Menu system and the FORTRAN interface system.

MENU SOFTWARE. This is referred to as control software since it provides the user a capability for exercising the computer system, processing functions, and hardware peripherals. It is designed to be a tool since it is highly user-oriented and, as such, it has been tailored to the needs of the user who has customarily utilized light tables and microscopes for the extraction of information from photography. With MENU software, the non-computer-oriented is led through such image processing operations as search, scale, rotate, translate, generate subimage, reformat, remap grey levels, etc. Some of the display operations include display entire image or subimage, erase screen, save image, edit images, etc. Generally speaking, many application programs exist within the MENU system. There are approximately 80 different operations in this system and it is designed to assist a photo interpreter in making decisions quickly and accurately.

FORTRAN INTERFACE SOFTWARE. This body of software allows the user to access his own FORTRAN programs using system routines for input/output and to execute them from the Tektronix terminal. It also allows communication with the STARAN via FORTRAN -- callable, routines in addition to allowing use of the Tektronix and COMTAL displays via FORTRAN-like statements. Not much else will be said of this software other than to emphasize the fact that implementation of digital image processing applications can be accomplished quickly since the system software handles all the data management thereby relieving the researcher of this burden. He is free to quickly develop applications in this FORTRAN environment and speed up the research in digital image processing.

APPLICATIONS

We will present results of several functions which a photo interpreter performs in carrying out military intelligence operations along with a few simple mapping functions. These results were obtained by writing application software using the FORTRAN interface software system.

All of the following photographs were taken on the face of the COMTAL displays using a polaroid camera and do not reflect the true resolution of these displays.

Military Intelligence-Scroll/Magnify/Mensurate/Target. These functions are depicted in several of the following photographs. However, they were performed on the same image as the image was being scrolled on the displays by the photo interpreter. It indicates the multi-function capability of the system under operator control.

Scrolling is an important data handling function since it allows a photo interpreter to quickly scan a large image at reduced resolution and pick out areas for closer investigation at full resolution. The technique is analogous to moving map displays except here we are moving a digital photograph and much more data. For example, Figure 3 is a reduced resolution photo of a 2,048 x 2,048 pixel, 8 bits per pixel image stored in the interactive system data base. It contains approximately 32 million bits of information and not all of this data can be displayed on the COMTAL screens because they are limited to 512 x 512 pixels, 8 bits per pixel. Therefore,

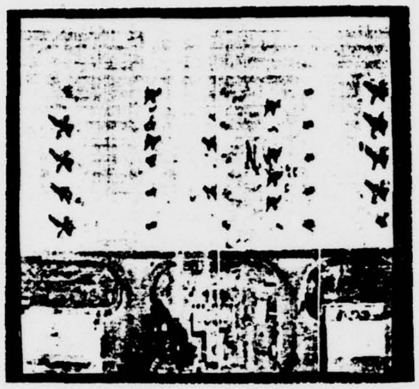

Figure 3. Reduced Resolution/Scroll

the scrolling operation requires that not more than every fourth pixel be fetched from the data base, a line at a time, and moved to the COMTAL displays. The software required for this seemingly simple operation is complicated if it is to be made efficient and a simple, brute-force approach only slows the process and defeats the objectives of an efficient interactive system. Efficient scrolling requires indepth system knowledge of the CDC-6400 controller, channel coupler, PDP-11/50, and the COMTAL display system.

The rectangle superimposed on the reduced resolution image of Figure 3 indicates the fast graphics capability of the system and here it is used to indicate the area which is being scrolled at full resolution on the second COMTAL display. Figure 4 is a portion of this area within the rectangle whereby the interpreter stopped the scroll and began other operations. In this case, he wishes to

Figure 4. Scroll/Magnify/Mensurate

extract additional information about a fighter plane parked on the runway. Figure 4 is a four-time, digital enlargement of the airplane, and it is accomplished using a bilinear interpolation process whereby a pixel and its neighbors are used to create additional pixels.

Mensuration is also depicted in Figure 4 in which the interpreter measures the body length and wing/body angle. This is accomplished by successively placing the cursor at both ends of the body and the length is computed almost instantaneously using parameters of the photo such as its scale. Similarly, the angle between the wing and the body is computed by placing the cursor in three successive positions and the result is produced as quickly as the length mensuration. Both length and angle are displayed on the COMTAL screen and these results can be saved by assigning a new name to the image and stored back into the digital data base.

Targeting is depicted in Figure 5. Here, the same image is

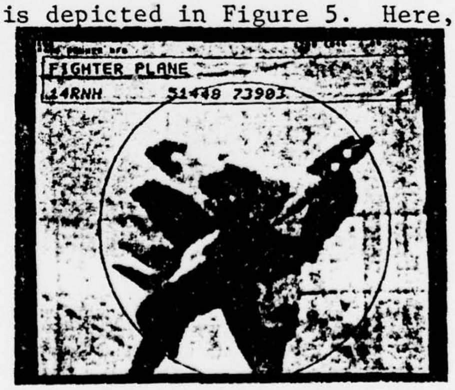

Figure 5. Scroll/Magnify/Target

used by the interpreter but now he wishes to obtain its Universal Transverse Mercator (UTM) grid coordinates. This is a valid, world geodetic coordinate system, and it requires preliminary preparation of the digital photograph in order to place it into this system. We will not discuss this process since it is complex and lengthy. Let it suffice to say that once the data base is prepared, target coordinates are obtained as quickly as mensuration results. The results of a targeting exercise is shown in Figure 5 and the UTM zone number, Northing and Easting and image name are shown on this photo again using the fast graphics capability of the COMTAL system. The coordinates are relative to the center of the circle where the operator placed the cursor.

Once these operations are completed to the satisfaction of the interpreter, he can continue the scroll until the entire area within the rectangle has been searched at full resolution. Of course, there are numerous other functions which he can perform such as grey-scale remapping as the scroll continues; that is, he can digitally change the contrast of the photo under cursor control concurrently with the scroll. This operation requires that both the PDP-11/50 and CDC-6400 work concurrently and in real time.

Military Intelligence-Digital Filtering. Many times a photo interpreter is confronted with suboptimal photography thereby hindering the interpretation process. Such is the case depicted in Figure 6, and Figure 7 represents the digitally filtered image. The original

Figure 6. Original

Figure 7. Filtered

image took on a half-tone appearance in the printing process which masks out details such as the separation between vehicles in parking lots. These figures are digital enlargements of the pre- and post-filtering operation and were digitally extracted from their larger counterparts.

The original enlarged image is 512 x 512 pixels by 8 bits per pixel, and it was passed through the Fast Fourier Transform (FFT) software package residing in the parallel processor side of the interactive system. The FFT is one of those algorithms which is amenable to being executed in parallel, and the STARAN performs this operation approximately ten times faster than the sequential processor. It is clear that the filtering process removed the half-tone appearance and that it provides a better chance of interpreting the contents of the photo.

<u>Mapping Functions -- Profiling Contouring</u>. Line-of-sight problems are commonplace in a field army environment. Figure 8 represents discrete elevation data encoded with grey shades, and the profile between the points connected by the line is shown in Figure 9. In

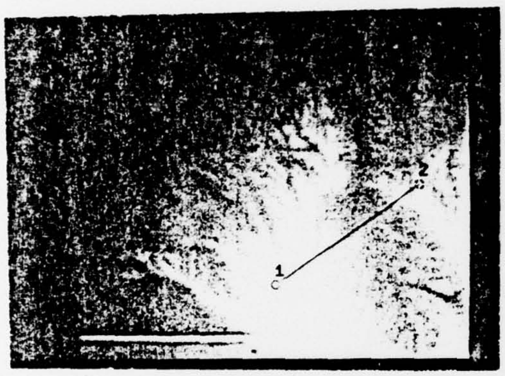

Figure 8. Gray-Shaded Elevations

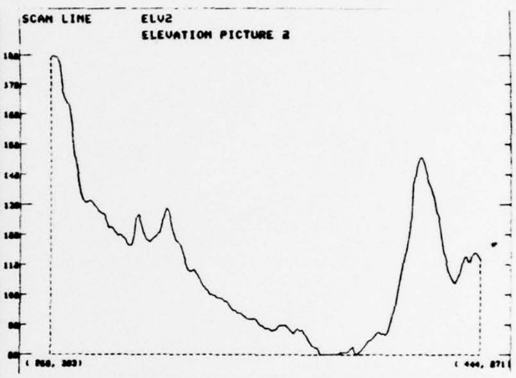

Figure 9. Profile

order to produce the effect shown in Figure 8, 250,000 elevation points were selected from a section of a topographic map and grey-shade values assigned to them. The lowest elevation was assigned black, the highest value was assigned white, and several other grey values were assigned to those in between elevations, thereby resulting in pseudo three-dimensional representation of the terrain.

Application software was written to allow the operator to select the end points of a desired profile by using the cursor. That profile is then output on a hardcopy device at the operator's terminal. The profile shown in Figure 9 indicates that an observer is not able to see from point 1 to point 2. This can almost be assumed by viewing the grey values at these two points in that point 1 is almost white, while the line to point 2 transverses white areas also. However, the computer is a better judge of the grey value at specific points than the human eye, and in addition, the profiling process is completed in less than 2 seconds.

The digital image created from these elevations can also be "quick contoured" by assigning colors to bands of grey values (elevations). The original image is assigned a different color than those chosen for contours so that they become more vivid on the display. The result of this process again takes place in real time and is shown in Figure 10. Although the image is shown here in black and white, a vivid contouring operation is displayed on the COMTAL

Figure 10. "Quick" Contouring

screen in pseudocolor. There have been many comments concerning the usefulness of pseudocoloring, and a favorable one is that it indicates subtle changes in the grey shades better than black and white.

Weapon Products -- Pershing Missile. The Army's Pershing missile system is terminally guided to its target by an electro-optical device called the "correlatron." It is housed in the missile along with a Plan Position Indicator (PPI) radar which scans the target area at several elevations during its downward flight. The "live" radar scene is correlated with a prestored, synthetic scene within the correlatron. The match, or mismatch, between these scenes provides the guidance information. Our concern is with the generation of the synthetic scene, and the part played by the digital interactive system.

Synthetic radar scenes are generated from elevation and cultural data bases where slopes derived from the elevations are used to predict radar returns along with returns predicted from the cultural information, such as bridges and buildings. Currently, the initial synthetic scenes are produced in a batch computer environment and the digital, interactive processing begins with this product to make them look even more like the live scene. Live scenes of targets have been digitized, and, as the interactive process progresses, the continually modified synthetic scenes are correlated with live scenes. Correlation curves and statistics are output at the operator's terminal, and the correlation is performed in the parallel processor.

Figure 11 is a synthetic scene produced in the batch computer environment, and Figure 12 is the result of many modifications to the initial synthetic scene. The correlation curves are shown in Figures 13 and 14, where the former indicates poor correlation and the latter good correlation since it has a pronounced peak as opposed to the flatness of the former. The good correlation curve was obtained

Figure 11. Original Synthetic Scene

Figure 12. Modified Synthetic Scene

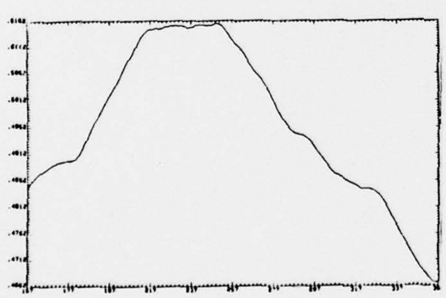

Figure 13. Poor Correlation

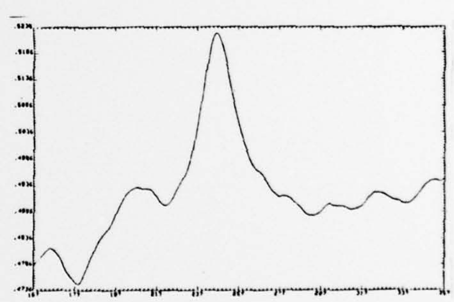

Figure 14. Good Correlation

after numerous changes to the original synthetic scene, but the correlation was carried out after each change in order to monitor its effect. Correlation is performed by moving the digitized live radar image in a horizontal and vertical fashion over the entire modified synthetic scene, thereby producing 240,000 correlation numbers which are used to produce these curves. This is accomplished in a few seconds on the parallel processor whereas a sequential computer would bog down in this operation. Only a few more seconds are required to display the results and obtain a hardcopy of the curve.

CONCLUSION

A great deal of effort has been expended in the development of the digital interactive system at the U.S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia. The results of integrating hardware, developing system and application software has been very encouraging since processes which took a week to accomplish in an ordinary computer environment are now taking only a few minutes. This speeds up the R&D process and offers an opportunity to see clearly the advantage of flexibility afforded by digital processing. Nevertheless, some basic problems remain and they will remain for years to come. As stated earlier, a characteristic of digital image processing is data volume. Until experience is gained with processing on conventional computers, it is difficult to assess the impact of digital image processing on these systems. Our experience indicates that it is very easy to inundate the system with digital image processing tasks because of this. This problem will be compounded in the future as acquisition systems of interest to the Army become digital. Also, it is very clear that certain tasks, such as correlation of digital imagery from stereopairs of photographs, is not relegated to the conventional computer because it is too slow for the production of elevation data. These problems, and more, will spur research in digital parallel processing.

We are looking forward to augmenting the existing system with advanced displays and other nonstandard digital hardware and software in an attempt to overcome some of these problems. This approach must be taken in order to demonstrate the practicality, cost effectiveness, and competitive nature of the digital approach relative to other technologies which could be used in performing functions such as those outlined in this paper. Performing the R&D in an ordinary, general purpose computer environment will always leave doubt concerning these attributes.

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